National Changes in Aquatic Habitat and Geomorphic Response to Urbanization, with Implications for Assessing Habitat Degradation

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BACKGROUND

Urban development affects stream hydraulics and sediment input, transport and deposition, thereby altering geomorphic conditions, aquatic habitat, and ultimately, aquatic communities. Responses of habitat and geomorphic characteristics to urbanization were examined in 249 streams from nine metropolitan areas across the U.S., including Portland, Oregon; Salt Lake City, Utah; Denver, Colorado; Dallas, Texas; Milwaukee, Wisconsin; Birmingham, Alabama; Atlanta, Georgia; Raleigh, North Carolina; and Boston, Massachusetts. A rural to urban land-cover gradient approach was used. Data were collected from 2000 to 2004, as part of a larger National Water-Quality Assessment Program study of urbanization effects on stream ecosystems.

Location of metropolitan areas sampled as part of the U.S. Geological Survey, National Water Quality Assessment Program study on the effects of urbanization on stream ecosystems, 2000–2004.

Habitat and geomorphic characteristics included descriptors of channel geometry and hydraulics, bottom substrate, reach volume, habitat complexity, and riparian/bank conditions. These characteristics were compared to several indicators of urbanization, natural landscape characteristics, and hydrologic metrics. To better understand local controls on urbanization effects, information on slope, channel modifications (channelization, bank stabilization, and grade control), and local presence of bedrock was also collected.

STUDY OBJECTIVES

- Describe local stream physical conditions associated with urbanization that influence aquatic communities (habitat as an independent variable)
- Determine stream physical responses to urbanization (habitat as a dependent variable)
- Identify potential regional and local controls on physical responses

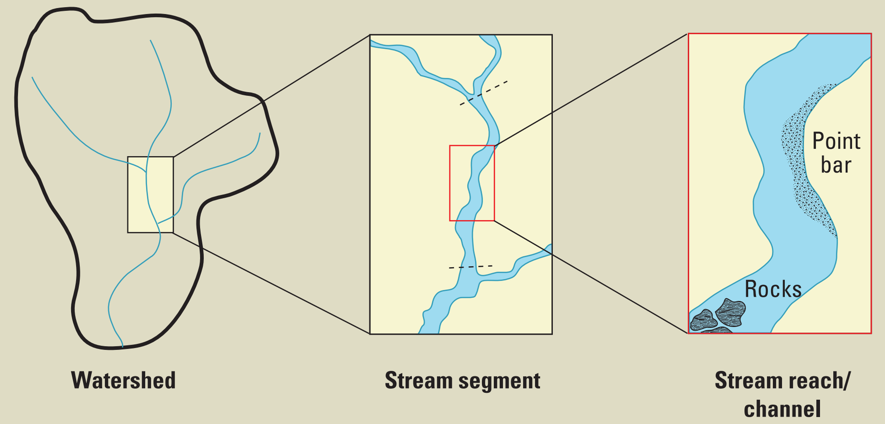
METHODS

Multi-Scale Assessments

Watershed-scale characteristics included land cover, soils, slope, road density, population and housing density, and drainage characteristics. These were calculated with a GIS for each basin upstream of the sampling site. Urban indicators included percent impervious surface, percent urban land, population density, proximity of urban land to the sampled reach, and road density.

Segment-scale characteristics were calculated for a 100-m buffer of the stream, begining at the sampling site and extending upstream to a distance related to drainage area.

Reach-scale habitat characteristics were measured at 11 transects during low flow and included bankfull channel dimensions, percent of geomorphic channel units, wetted channel dimensions, channel-bottom substrate, and bank conditions (substrate, percent and length of vegetative cover, angle, and percent erosion). At the downstream end of the habitat reach, water quality and biological communities were sampled. Hydrologic conditions were also measured at each site for one water year surrounding the sampling.



Watershed — Stream segment — Stream reach/channel

Data Analysis

Distributions of habitat/geomorphic characteristics, urban indicators, landscape characteristics, and hydrologic metrics were examined for the national data set and by individual metropolitan areas using scatterplots and boxplots.

Relations among variables were examined using Spearman rank correlation analysis for national relations as well as for each metropolitan area.

Urban indicators, landscape characteristics, and hydrologic metrics were considered independent variables. Some reach-scale habitat data were also considered independent variables, such as reach slope and riparian disturbed land cover. All other reach-scale habitat and geomorphic characteristics were considered dependent variables.

Stepwise multiple linear regression was performed on the national data set for a selected subset of habitat/geomorphic characteristics representative of channel geometry, bottom substrate, habitat volume, habitat complexity, and riparian/bank conditions.

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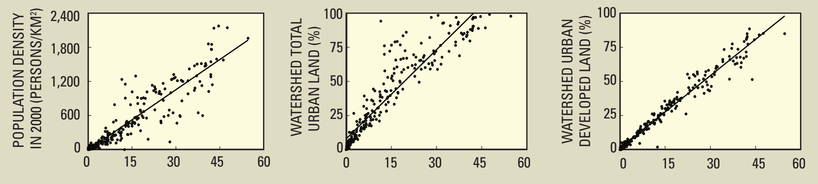
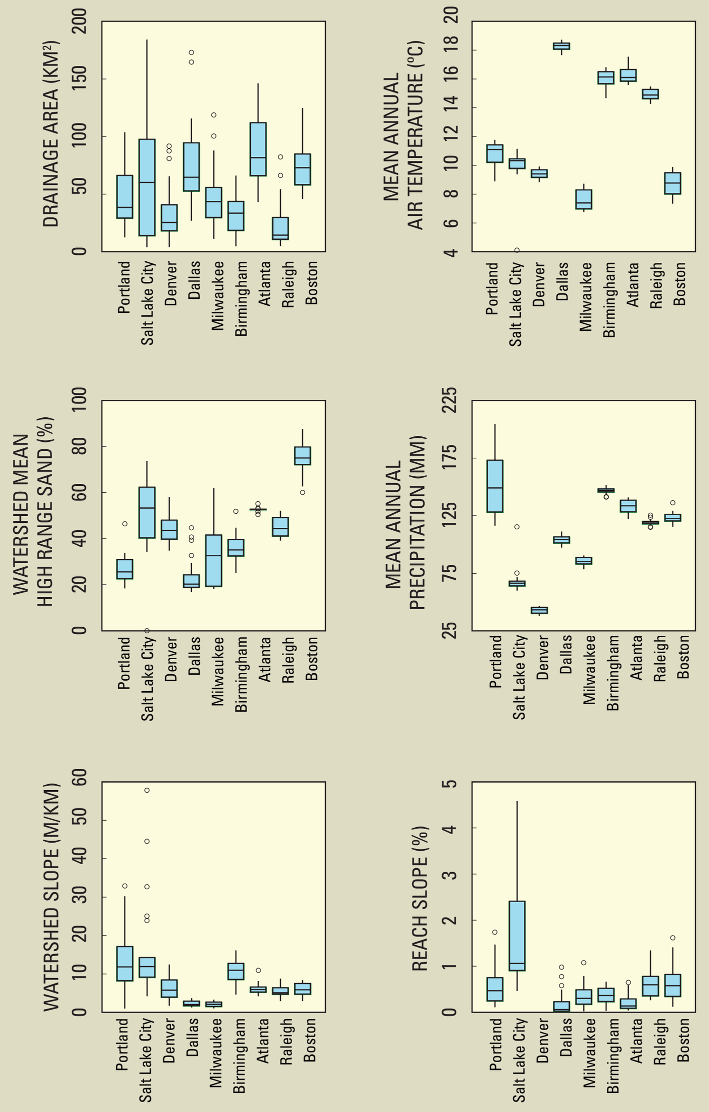
URBAN GRADIENT STUDY DESIGN AND LANDSCAPE SETTING

The rural to urban land-cover gradient approach for sampling assumes a space-for-time substitution of habitat and geomorphic responses to urbanization. About 30 streams were sampled from each of nine metropolitan areas across the U.S. Streams generally had drainage areas of less than 100 km² and similar physiography and climate within each area (see boxplots). Watershed topography was generally gentle and reach slopes were generally less than 2%. Channel types were generally single thread, meandering, and perennial.

Land cover in the low urban (rural) part of the gradient varied among forest, agriculture, and grassland (see stacked histogram). Rural areas in many watersheds were comprised of a variety of land cover types.

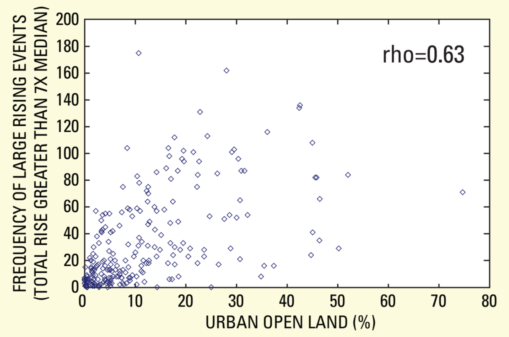
Watershed impervious surface was chosen as the indicator variable for degree of urban development. Generally completely urbanized watersheds had about 40–50% impervious surfaces and a population densities of 2,000 people/km².





Urban Open Land Cover

The percent of urban open land (parks, golf courses, school yards, areas around airports or highways, as well as large-lot residential areas) was highly variable among urban watersheds. On a national level, watershed urban open land had the highest Spearman correlation coefficient (rho of 0.63) with the frequency of large flow events compared to other urban indicators such as impervious surface (rho of 0.38). Causes for the relation are not known; however it may be reflecting drainage network connectivity or runoff from compacted surfaces.



SW Prong Beaverdam Creek
Atlanta metropolitan area

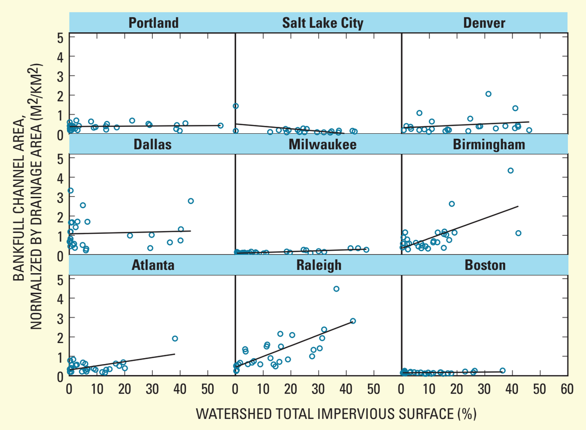
Urban developed land	19.48%
Urban open land	74.68%
Total urban land	94.16%
Watershed impervious surface	11.53%

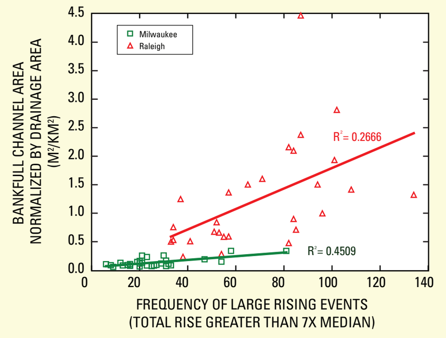
HABITAT AND GEOMORPHIC RESPONSES TO URBANIZATION

Habitat and geomorphic responses to urbanization varied by metropolitan area and were affected by regional climatic/physiographic conditions as well as local effects from reach slope, historical channel modifications, and presence of bedrock.

Channel Enlargement

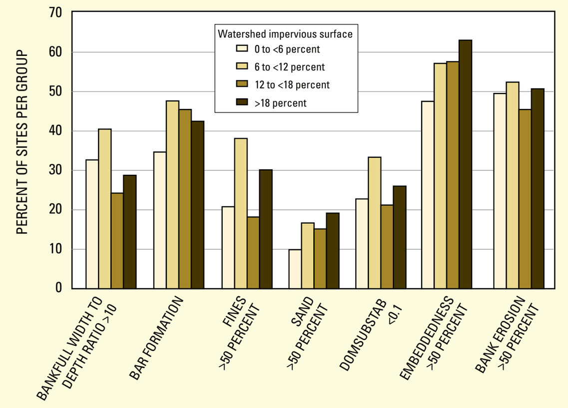
Channel enlargement was the most common response, especially in Southeast and Midwest metropolitan areas. The magnitude of the response was dependent on rainfall intensity and soil types. The lack of channel enlargement in Portland, Salt Lake City, Denver and Boston was likely due to pre-urban hydrologic and channel alterations—from interbasin transfers and diversions and storage in the West to abundant millponds in the Northeast.



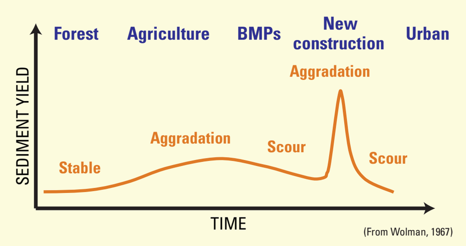


An increase in the frequency of large high-flow events related to channel enlargement was the most common hydrologic response to urbanization.

Channel Shape and Substrate Changes



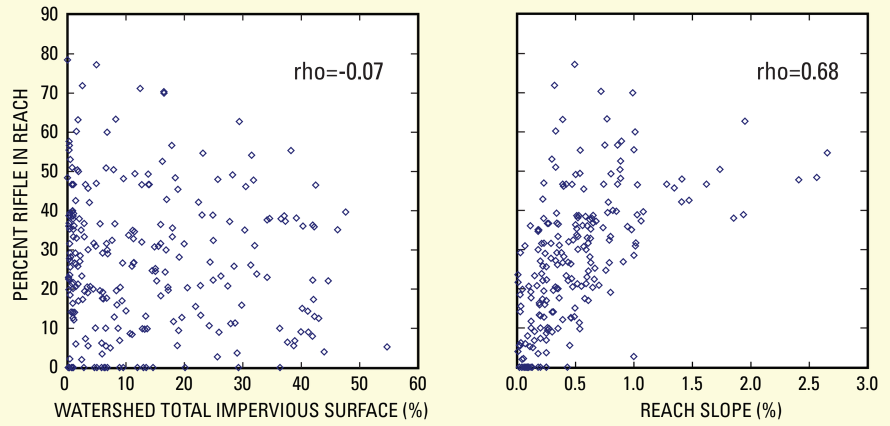
Possible change in sediment yield with urbanization



Channel shape and substrate changes associated with urbanization were not observed in this study. These characteristics are dependent on slope, parent material, alluvial setting, upstream sediment loads (both suspended and bedload), and sediment transport capacity. For example, depending on the geomorphic setting, some stream substrates may coarsen from incision, while others become choked with sand.

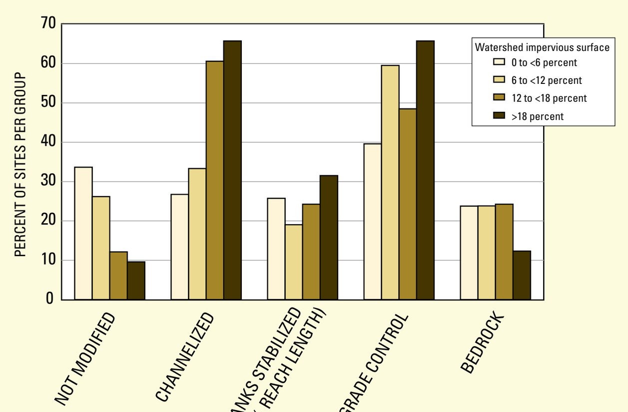
Preliminary results from grouping sites into four categories of urbanization suggest that channel shape and substrate changes do not follow a monotonic trend with urban development but vary temporally. The amount of fines and bar formation are highest at initial development (6-12 percent watershed imperviousness). Streams with the lowest substrate stability also were in this category of urbanization.

Habitat Complexity



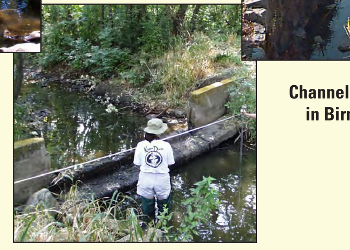
We used the percentage of riffle habitat as a simple surrogate for habitat complexity. The percentage of riffles was not affected by urbanization, indicating that channel geomorphic units are less sensitive to urbanization than other geomorphic features. Instead, the amount of riffles was dependent on a relatively small range of reach slope. Generally reaches with higher than 0.5 percent slope had greater than 20 percent riffles. Geologic setting, parent material, and bedrock were also important.

Channel Modifications



A large percentage of the sampled streams from all metropolitan areas had artificial channel modifications. Over 60% of urban streams were channelized and had grade control structures. Over 30% had bank stabilization. Many of the rural stream channels were artificially altered. It would be impossible to sample only natural channels. These features need to be quantified if habitat *responses* are the main goal of the study.

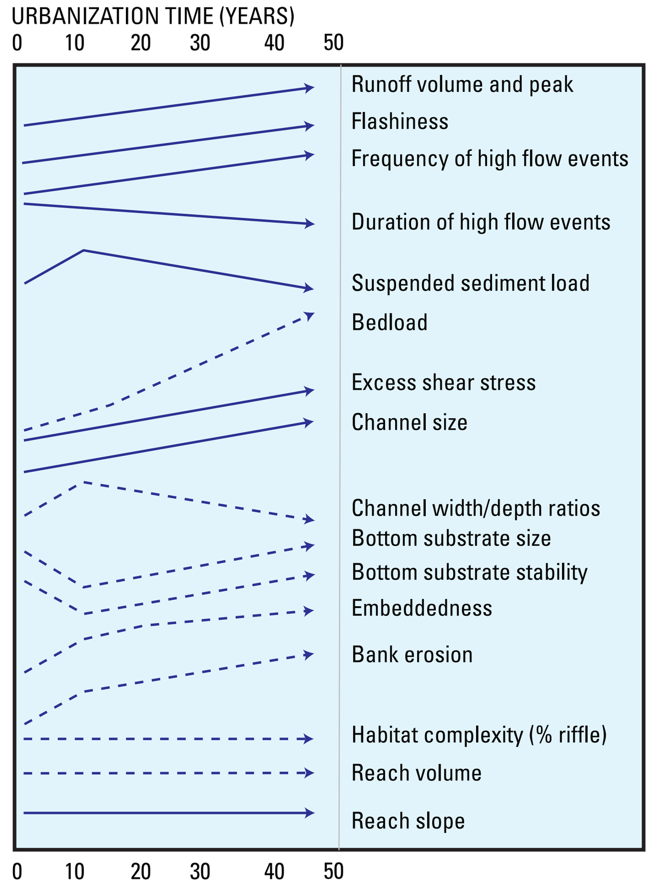
Bedrock channel in Raleigh metropolitan area



Grade control structure in Salt Lake City metropolitan area

Channelization and bank stabilization in Birmingham metropolitan area

SUMMARY AND CONCLUSIONS



This diagram summarizes the most common habitat and geomorphic responses to urbanization found in this study and other studies in the literature. Time scale is based on temporal studies of urban streams in the eastern U.S. (Leopold, 2005). Spatial scale is based on this study. Solid lines are responses typically observed in this study and other studies. Dashed lines are potential responses. All responses are dependent on watershed climatic and physiographic setting. Channels are assumed to be alluvial, nonbedrock, and not influenced by historical or recent changes in stormwater management, bank stability, or grade control.

- **Channel enlargement is the most common response to urbanization.**
- **Channel shape and substrate conditions vary temporally with degree of urbanization and changes in the sediment regime associated with stages of urban development.**
- **Channel geomorphic units, such as riffles, are dependent on local slope and geologic setting more so than urban development.**
- **Historical watershed and local channel modifications confound expected relations.**

FUTURE NEEDS

Watershed-Scale Needs

- More quantitative information on stormwater management practices
- More detailed drainage network delineation for urban watersheds
- For Western streams, more quantitative information on interbasin transfers, diversions, and storage
- Better understanding of hydrologic responses for urban open land (grassy areas associated with parks, golf courses, school yards, areas around airports or highways, as well as large-lot residential areas)
- More quantitative data on connectivity of impervious surfaces
- More temporal data on changes in sediment loads (total) and transport related to stages of urbanization

Water diversion structure Salt Lake City metropolitan area

Local Controls on Physical Responses

- More information on local geologic setting and presence of bedrock
- More data on rural and urban historical channel modifications such as channelization, mill dams, grade control, bank stability, and road crossings
- More data on temporal changes in sediment transport capacity

Restoration project, November 2001 Milwaukee metropolitan area

Completed project, August 2004 Milwaukee metropolitan area

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For more information, see the National Water Quality Assessment Program Effects of Urbanization on Stream Ecosystems (NAWQA EUSE) website:

http://co.water.usgs.gov/nawqa/EUSE/